Association of Wet and Dry Periods in Northern California and SSTs in the Pacific Ocean

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Abstract

In a Mediterranean climate like California it is not unusual to experience extended dry periods. In fact if one analyzes independent rainfall samples (Northern CA 8-station index, San Francisco downtown (SFD) gage and Central Coast Climate Region from WRCC) by water year rainfall anomalies ,smoothed to remove higher frequency variability , there are repeatable dry and wet cycles observed in the historic record back to the turn of the 20th century. It has been noted that extended dry periods (three consecutive years below normal) become critical for adequate water supply in Northern and Central California. This has been well documented during this past three year drought (2007-2009). This short paper attempts to determine if there are any relationships between inter-annual changes in tropical SST's such as the ENSO (El Nino Southern Oscillation) cycle and/or decadal variations in Pacific SSTs (Pacific Decadal Oscillation- PDO) and predictability of these wet and dry cycles. Individual SFD water year (October 1 through September 30) anomalies are also analyzed with respect to ENSO strength. This was done specifically to address annual winter weather briefings given to county officials each fall; and whether more definitive guidance could be provided on the possibility of continued drought or drought relief.

1. INTRODUCTION

Those who have been forecasting for any length of time in California have the perception that annual rainfall can be categorized as feast or famine; either too much or too little. These wet and dry years can be consecutive and lead to years of water abundance and potential flooding, or water deficits leading to severe water restrictions. It is well documented (DWR, 2008 and (**http://www.water.ca.gov/drought/docs/hydrology_drought-1987-1992.pdf**) that consecutive dry years, usually 3 or more (a dry year or consecutive years relate to Sierra runoff in the lowest 10% of the historical range, and reservoir storage during the same time period of less than 70%) signal drought conditions. There were 6 statewide droughts during the 20th Century or about one every 16 years. This study is an attempt to determine if there are any relationships between wet and dry years or extended wet and dry cycles and tropical Pacific and Pacific oceanic temperatures. There is a wealth of literature that has looked at relationships between Pacific SSTs and precipitation along the West Coast (Cayan et al, 1999, McCabe and Dettinger, 1999, Hoerling and Kumar, 2002, MO, 2010) both on annual and decadal time scales. The standard set of observations used to estimate water supply for the coming year is the Northern California 8-station Index, Figure 1. Records date back to 1921. Other historical rainfall observations include the San Francisco downtown climate site with continuous records back to 1849, the longest continuous rainfall measurements on the West Coast. Finally the Western Region Climate Center (WRCC) has compiled regional climate zones within California that extrapolate water year (WY) rainfall back to 1896. These independent data sets appear to confirm the large scale wet and dry cycles for WYs in California as they have correlations of .91 to .93 among each other. This study will try to focus on the San Francisco record as it provides the best historical record for the San Francisco Bay Area WFO County Warning Area.

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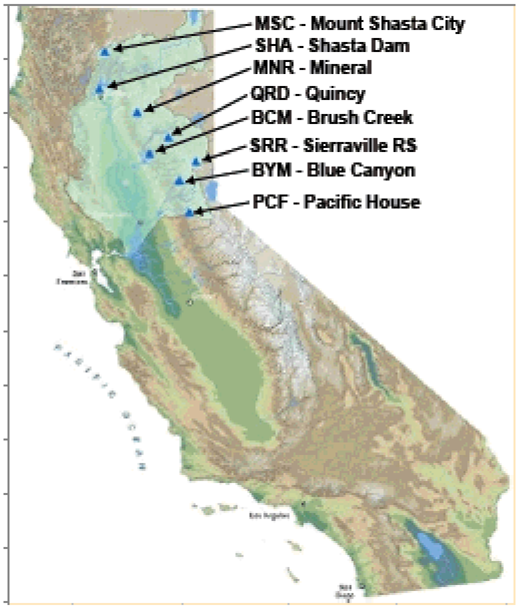

Figure 1. Location of 8 gage locations that make up the Northern California 8-station index. The location of the San Francisco downtown gage is also noted.

2.0 DATA SETS

The precipitation data sets used for this study, as noted in section 1 above, included the 8-station index gages available from 1921 through WY 2010 (http://cdec.water.ca.gov/cgi-progs/precip1/8STATIONHIST), shown in Figure 1, the San Francisco downtown cooperative observer site, available from WY 1850 through 2010, and the Western Region Climate Center WestMap Climate zones shown in Figure 2 (http://www.cefa.dri.edu/Westmap/) available from 1896 through 2009. The water year rainfall was converted to normalized anomalies by the following method:

- **Normalized Anomaly used for this study:**
  - ***Average WY Rainfall SFD = 20 in***
  - ***If observed WY rainfall SFD = 40 in***
  - ***Anomaly = 40/20-1 = 2-1 or 1***
  - ***Thus 0 = average rainfall***
  - ***1 = twice normal***
  - ***-.5 = half normal***

The ENSO index used in the study is the MEI or Multivariate ENSO Index (http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/). Only the Oct-Nov MEI value was used in this analysis to provide a predictor to the WY precipitation. This index provided the highest correlation to the rainfall data used. It is only available back to 1951.

The Pacific Decadal Oscillation Index was obtained through the following web site (http://jisao.washington.edu/pdo/PDO.latest). Again only the 3 mo PDO index from September through November was used as a predictor for the WY rainfall.

SST data for a location off the central California coast was used to compare to rainfall data. This was obtained from the following website (http://wxweb.meteostar.com/SST/index.shtml) which is reproduced from the Hadley Center.

Another index used to determine if other mid-latitude forcing might be controlling WY precipitation was the 3 month (Dec-Feb) Tropical Northern Hemisphere teleconnection pattern (TNH) (ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh). This index is calculated for the period Dec – Feb back to 1950. This index is negatively correlated with west coast precipitation as seen in Figure

4 (http://www.cpc.noaa.gov/data/teledoc/tnh.shtml). This index does account for a shift in the Pacific jet stream and a weaker Hudson Bay low. A TNH of -3 would index a well south displacement of the Pacific jet and much weaker Hudson Bay low. A +3 would be just the opposite. Note that this only accounts for the primary winter months and does not represent what could be spring rains.

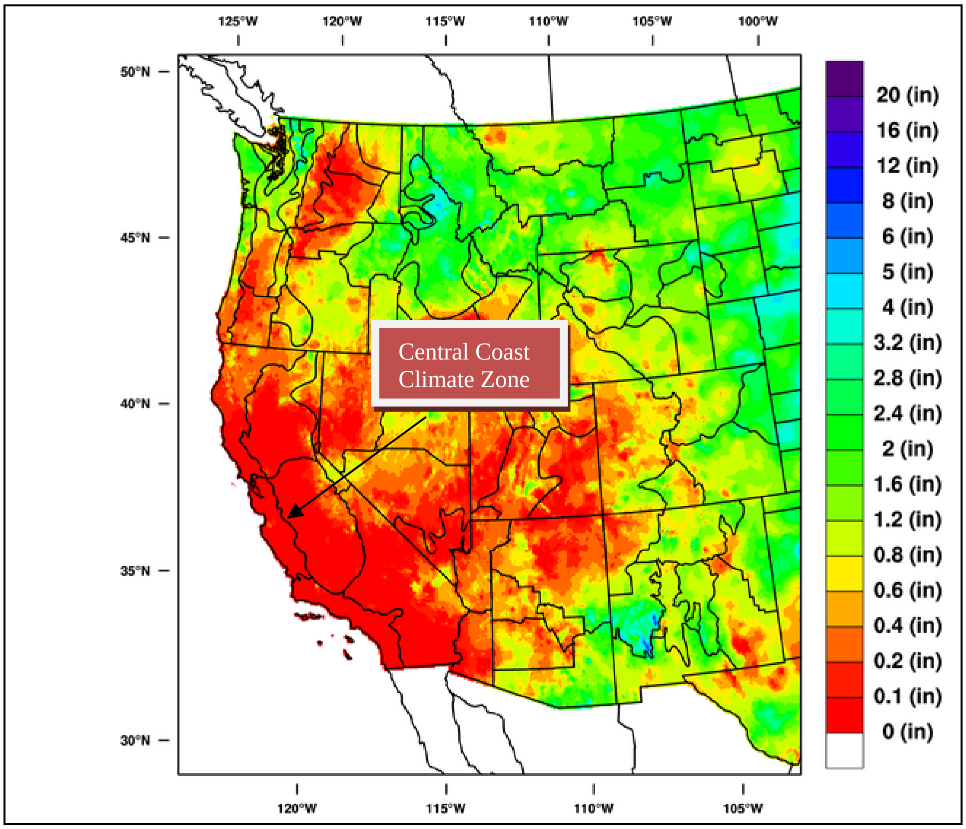

Figure 2 WRCC climate zones with extrapolated WY precipitation dating back to 1896.

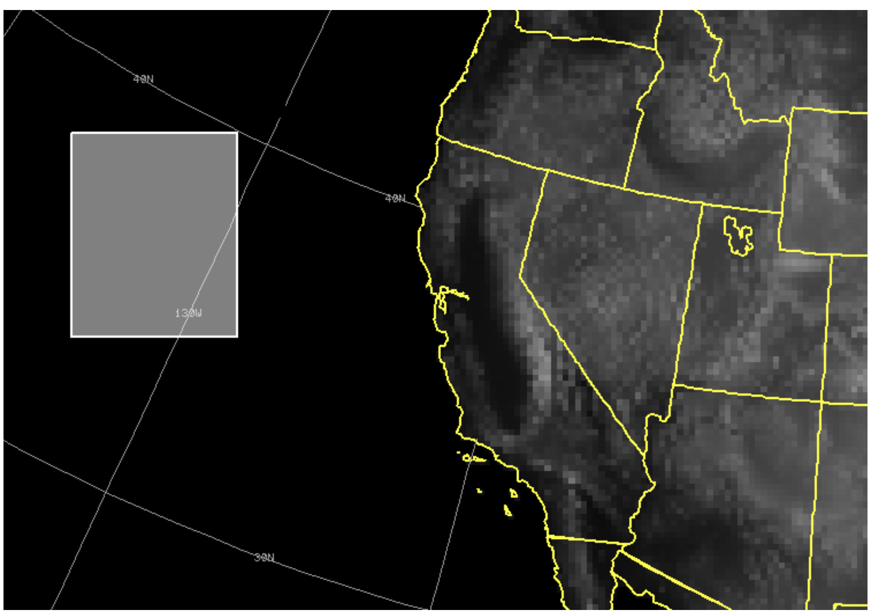

Figure 3 Approximate area used to extract SST data off the coast for comparison to precipitation and PDO ENSO indices.

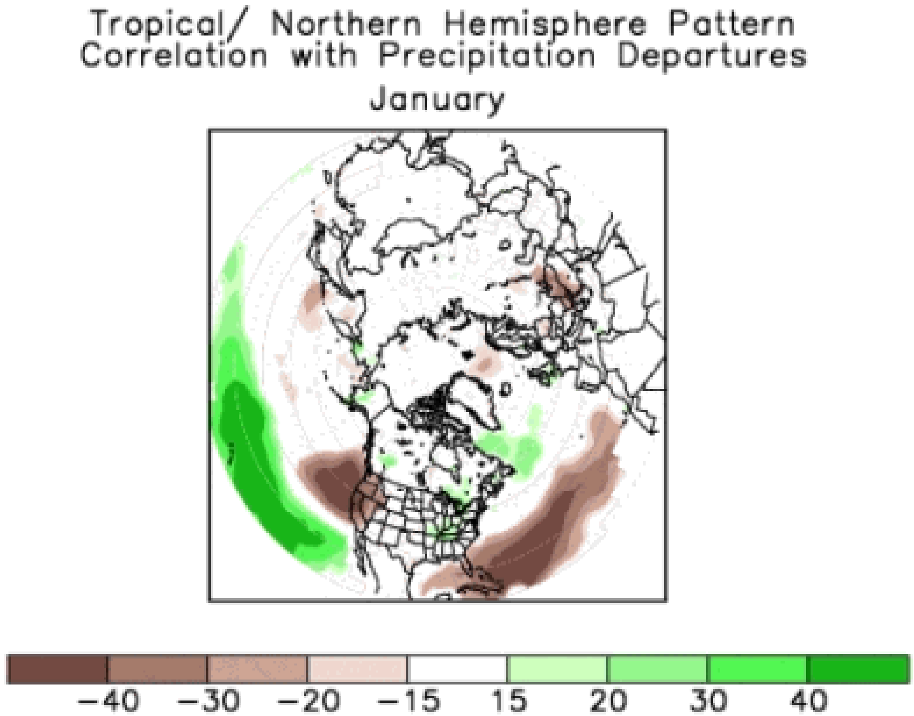

Figure 4 Positive Tropical Northern Hemisphere teleconnection correlation to January precipitation.

3.0 ANALYSIS

3.1 Trends Analysis

Figure 5 displays a smoothed analysis of the 3 independent WY precipitation data sets using a Fast Fourier Transform (FFT) to remove higher frequency variations. The purpose here was to identify extended wet and dry periods in northern and central California. The extended below normal periods identified were then compared to the 4 drought cycles noted by DWR to have occurred in Northern and Central California since the turn of the 20th century. The identified drought periods were 1918-20, 1929-34, 1959-62, and 1987-92. The most recent dry period of WY 2007-09 is evident but not of the magnitude of some of the earlier dry periods. There are other meteorological dry periods seen in the record such as 1945-48, and 1975-76 (two driest back to back years on record), But these were not accompanied by extremely low reservoir levels so did not meet the criteria for water supply drought.

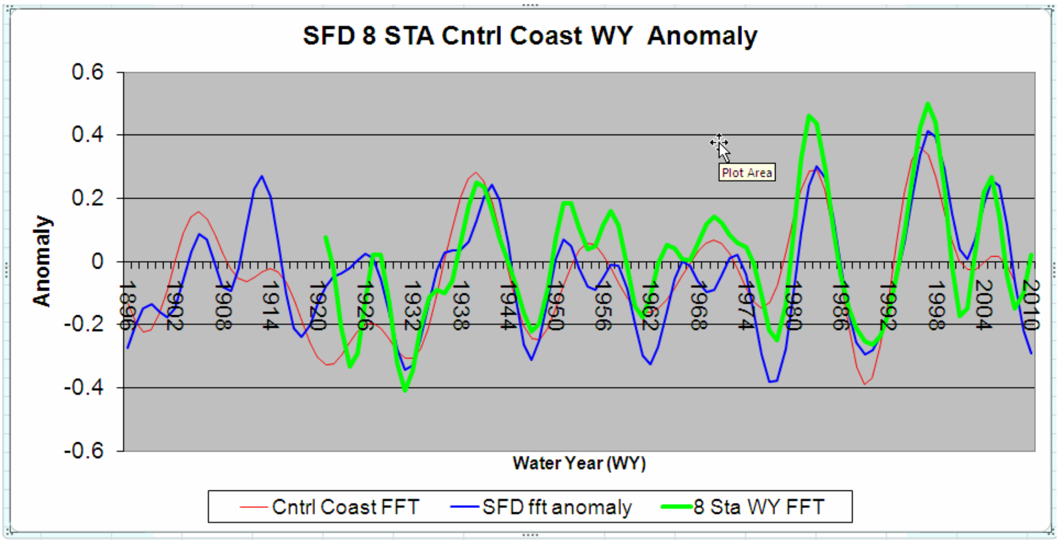

Figure 5 Three independent WY rainfall data sets smoothed (FFT used for smoothing using ITSM Software (Brockwell and Davis, 2002)) to show periodic wet and dry cycles for northern and central CA back to 1896.

The next analysis (Figure 6) was to compare these smoothed analyses to smoothed ENSO and PDO indices. To reduce clutter only the SFD data will be shown as the correlations to the Central Coast and 8-station index were .93 and .91 respectively.

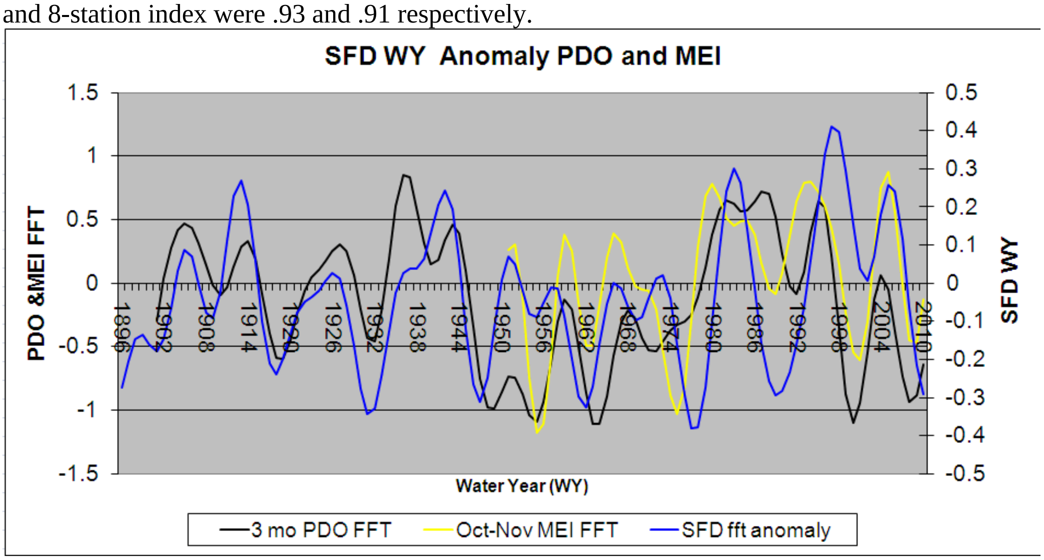

Figure 6 Analysis of SFD WY rainfall, Oct-Nov MEI and Sept- Nov PDO index.

In a broad sense there is a general positive relationship between trends in ENSO and PDO and SFD WY rainfall. Given that smoothing has been performed this might be producing some offsets in exact peaks and troughs in WY rainfall and trends in these indices. There does appear to be a general trend with the broad positive and negative phases of the PDO. The PDO was in the negative phase from 1915 to 1930, positive phase from approximately 1930 to 1945, the negative phase from 1945 to 1978, positive from 1978 through 1998, and negative from 1998 through 2010 and continues. Note that WY rain fall is generally below normal for years during the PDO negative phase with large excursions in both above and below normal rainfall during the PDO positive phase. Those years with strong positive ENSO signal, El Nino, can produce wet periods within the broader negative periods of the PDO. The WY 2006 is a good example. Note also that the wettest years appear to coincide with both the positive phase of the PDO and a strong El Nino; 1941, 1983, 1998.

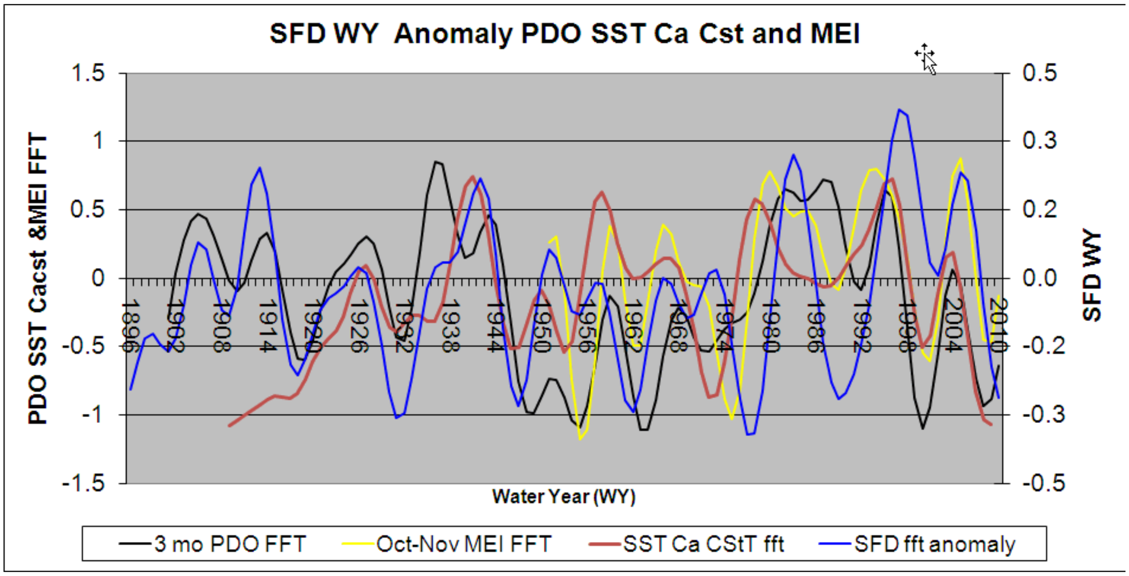

Figure 7 Same as Figure 5 with SST anomalies for SSTs from Hadley Center using area approximated in Figure 3.

In Figure 7 we have added the smoothed SST data from the sample area shown in Figure 3 dating back to 1909. The SST's are derived from the November through March period of the WY. There appear to be again some overall positive correlation between SSTs off the coast, PDO, ENSO index and WY rainfall. It has been speculated that if SSTs were warmer off the coast there may be higher moisture content for low-level winds to ingest this additional moisture content and bring it to the coast for orographic enhancement (Persson et al, 2005). Note also that the SSTs in the sample area are the coldest they have been since the first year of the data in 1909!

One last analysis was to look at the coefficient of variation (CV) using the water year rainfall from SFD to determine if variability relates to ENSO or PDO. The CV is simply the standard deviation divided by the mean of the sample. The CV was calculated for the period 1910 to 2010 and this is shown in Figure 8.

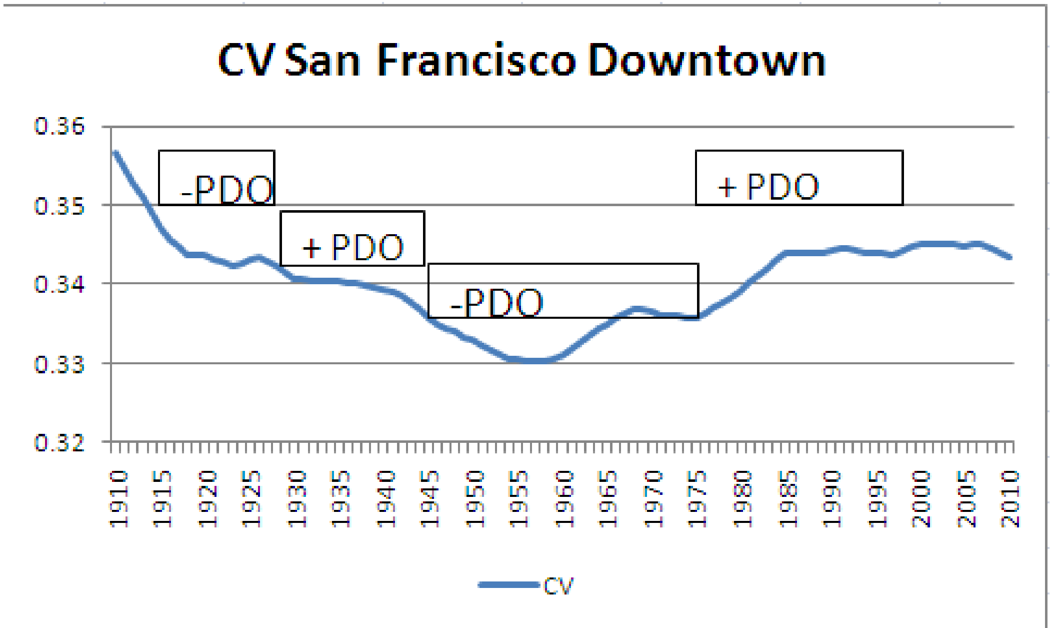

Figure 8 Coefficient of Variation (CV) for San Francisco Downtown for period 1910 to 2010 using a 10 yr running mean. Annotated on the chart are the period's that coincide with the positive and negative phases of the PDO.

The plot shows the CV varies on a time scale longer than the variations in the PDO. There was certainly a minimum in the CV near the middle of the 20th century and the CV rose abruptly from the 70s to the early 80s but appears to have leveled off at a similar level of variability to what was observed early in the 20th century. It should be noted that the CV was even higher in the late 19th century then at any time since (not shown). It has been noted by DWR (2006) that the increase in the CV from the mid 70s to the late 90s may be related to climate change inducing more extreme events. However this cannot be substantiated using the SFD WY data.

3.2 <u>WY analysis</u>

This section will look at the relationship between individual WYs using SFD and the MEI index. Each year was categorized as to ENSO strength using the following categories.

MEI >= 1.5 Strong El Nino
.5 <=MEI< 1.5 Weak to Moderate El Nino
-.5 < MEI <.5 Neutral
-1.5 < MEI < -.5 Weak to Moderate La Nina
MEI <= -1.5 Strong La Nina

Figures 9-13 show box and whiskers plots of the statistical WY rainfall distributions for each of the above categories.

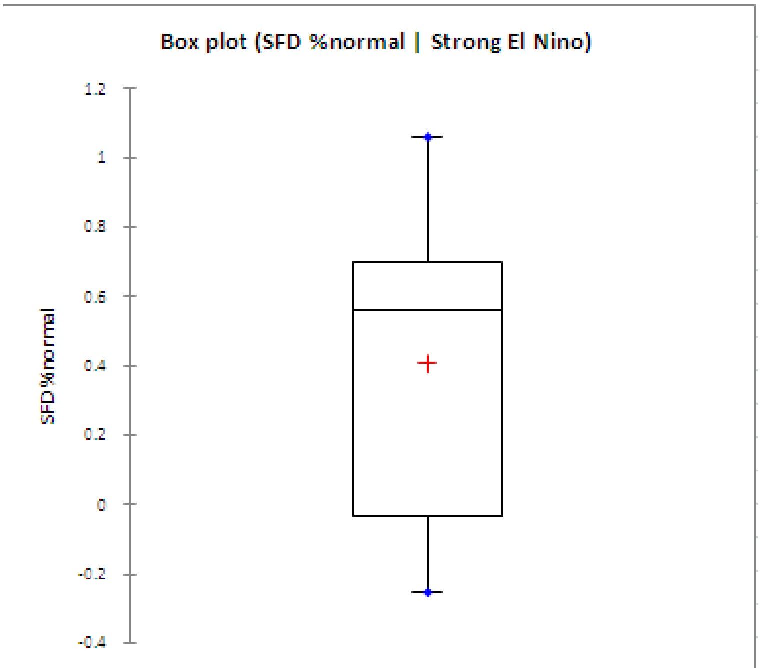

Figure 9 Standard box and whiskers plot of SFD WY rainfall for all strong El Nino's since 1951.

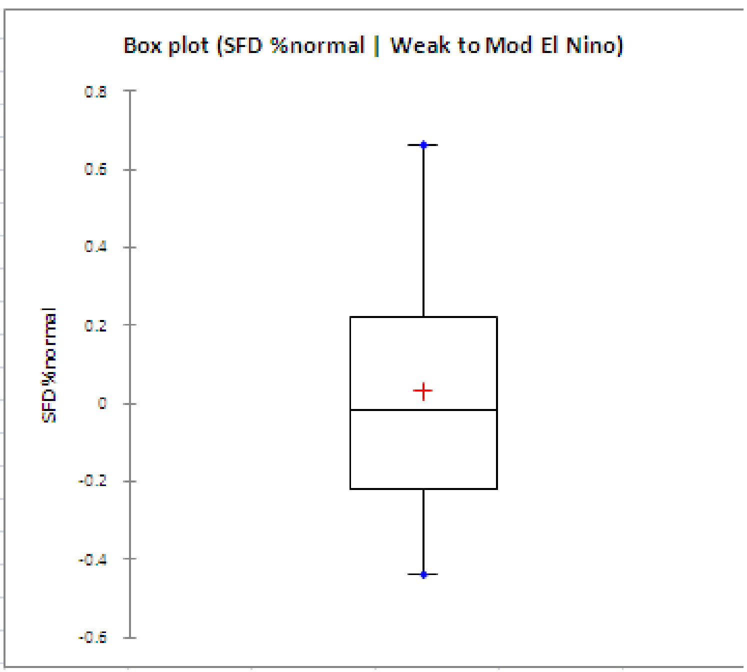

Figure 10 Same as Figure 9 only for weak to moderate El Nino's.

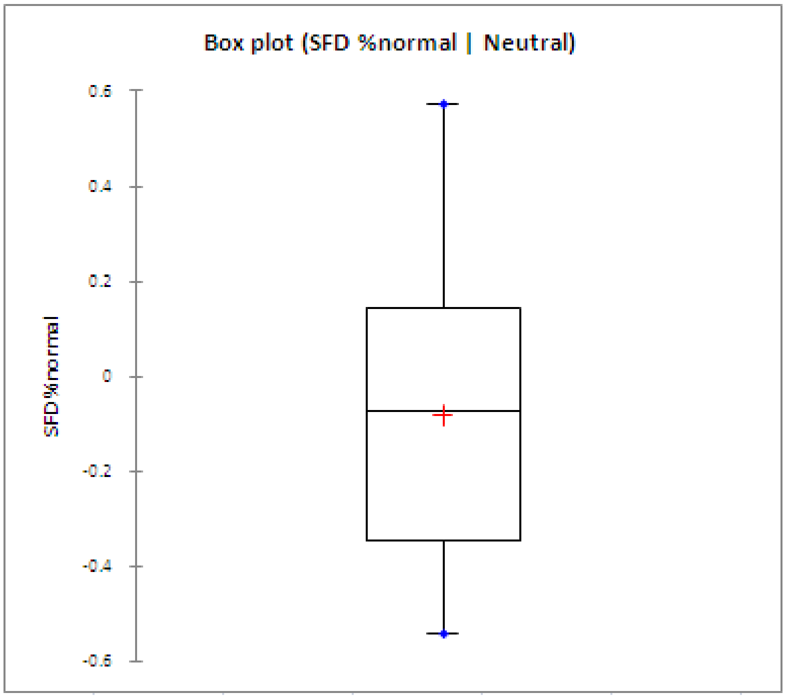

Figure 11 Same as Figure 9 only for neutral ENSO conditions.

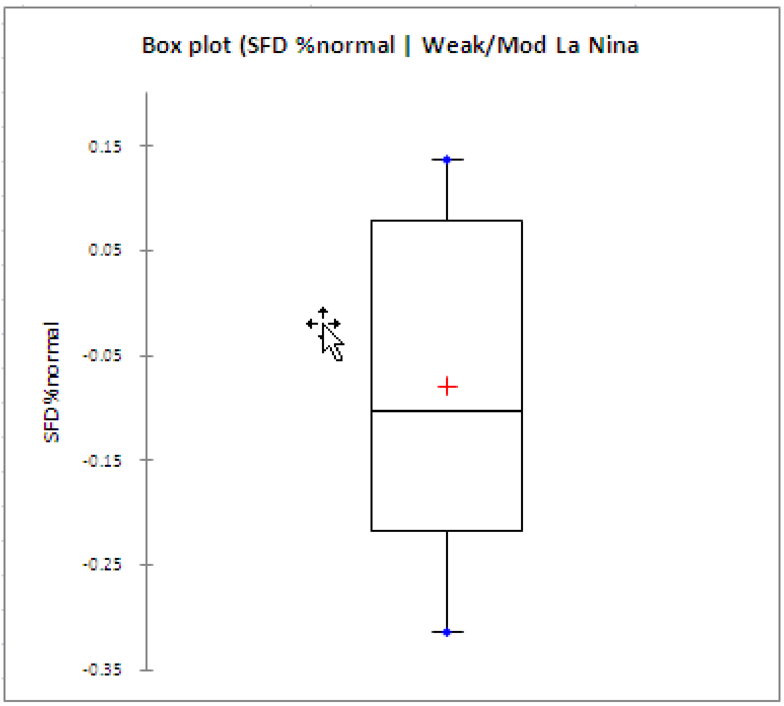

Figure 12 Same as Figure 9 only for weak to moderate La Nina's.

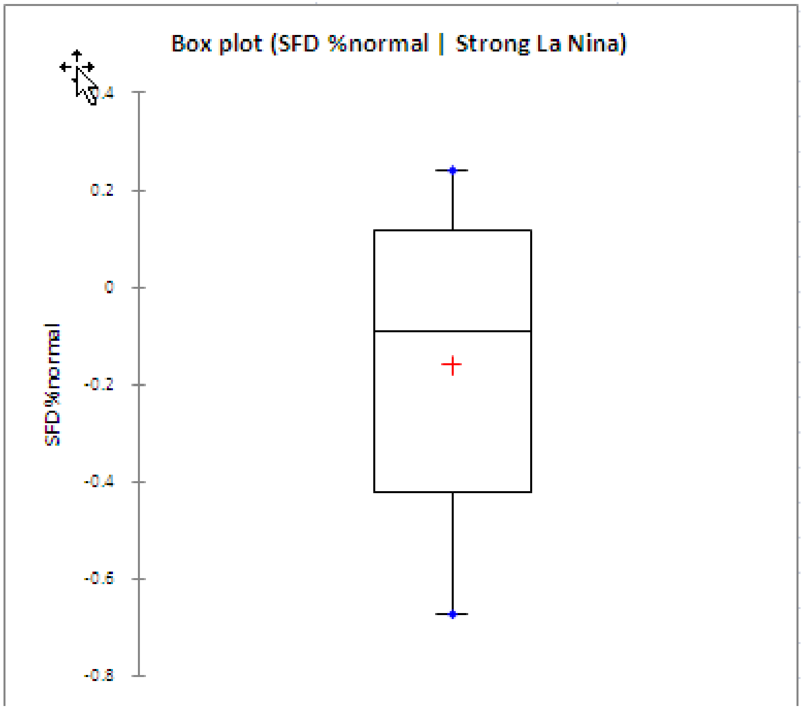

Figure 13 Same as Figure 9 only for strong La Nina's.

Statistically, strong El Nino's are associated with the wettest years while strong La Nina's produced the driest years. There are 6 cases for each of these two categories. The strong El Nino cases show that even the bottom quartile at normal rainfall. Only one of the 6 cases had below normal WY rainfall. Weak to moderate La Nina's (12 cases) have the smallest range of WY precipitation and are skewed to below normal rainfall in general. Neutral ENSO WY's (24 cases) show a considerable range as do weak to moderate El Nino's (12 cases). It would appear there is little predictive skill in Oct-Nov MEI and WY rainfall except for the strongest El Nino cases; and strong La Nina years where a predominance of below normal WY rainfall was observed.

To further investigate WY rainfall several x-y plots using color and symbol size for WY anomaly were created. The first of these is shown in Figure 14. Plotted in this manner one can see that in general there is a linear and positive relationship between the two predictors, fall PDO value and fall MEI index. One can

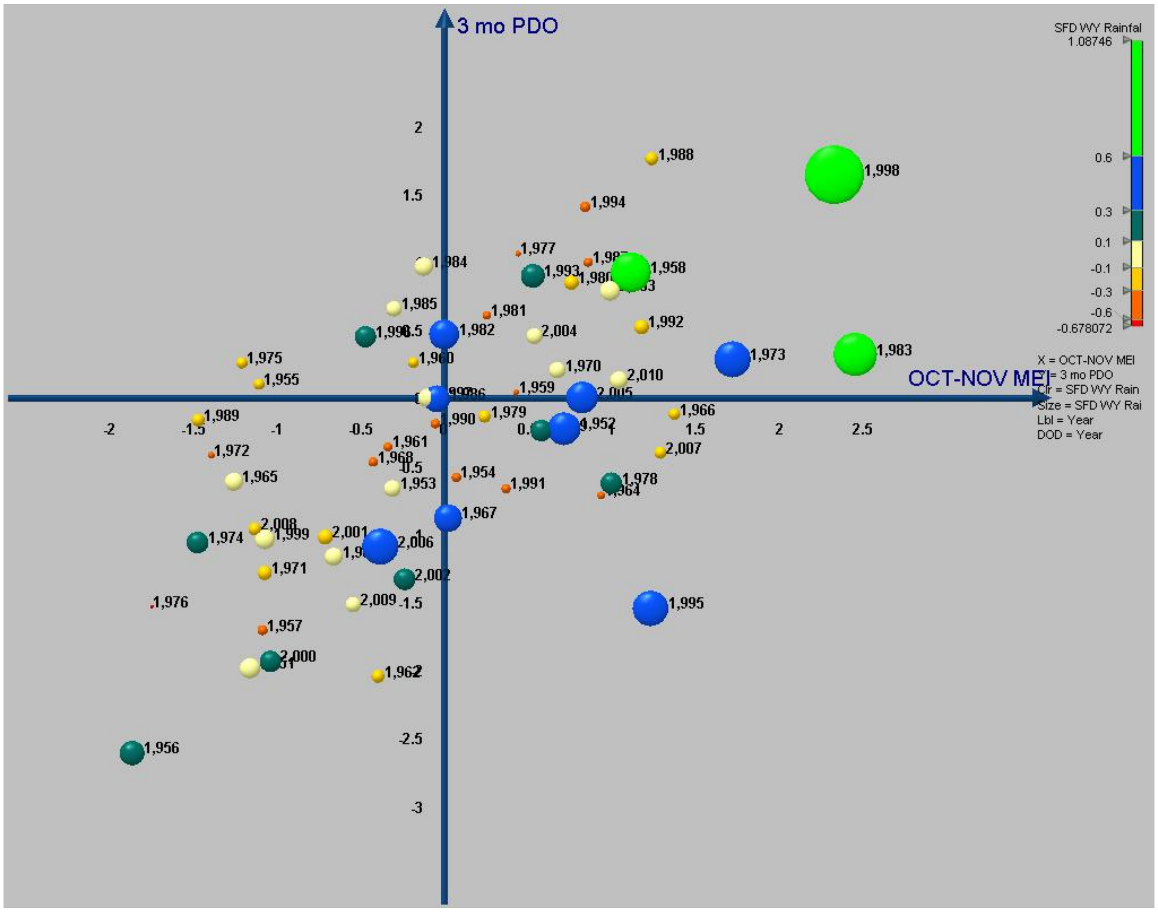

Figure 14 SFD WY rainfall anomaly plotted against PDO and MEI indices as shown. Color anomaly scale is shown in upper right. Size of the object is also related to WY anomaly. WY annotated next to object.

also note that the wettest years, bright green, 1998, 1983, greater than 160% of normal, are the two strongest El Nino's on record. There are other wet years, blue, of greater than 130%, that fall into weak to neutral ENSO and PDO conditions. Certainly 1995 stands out as having moderate El Nino strength but relatively strong negative PDO value. There may have been other extratropical forcing mechanisms in play for this year (see discussion below concerning TNH index). There are other years that are well above normal that are neutral ENSO such as WY 1982, 1986 and 2006. The February 1986 flooding and the late December 2005 and March 2006 flooding contributed significantly to the WY rainfall these years. The same can be said for 1956 seen in the extreme lower left corner of the plot. The historic December 1955 flooding was the major contributor to this WY rainfall.

In the paper sited earlier by Mo, it was noted that what was called the EPAC ENSO, or what we know as the conventional east Pacific warming or cooling in the ENSO 3.4 region, induces a response in the atmospheric circulation that resembles the TNH pattern. To validate this conclusion fall MEI is plotted against the TNH index instead of using PDO on the Y axis. This is shown in Figure 15.

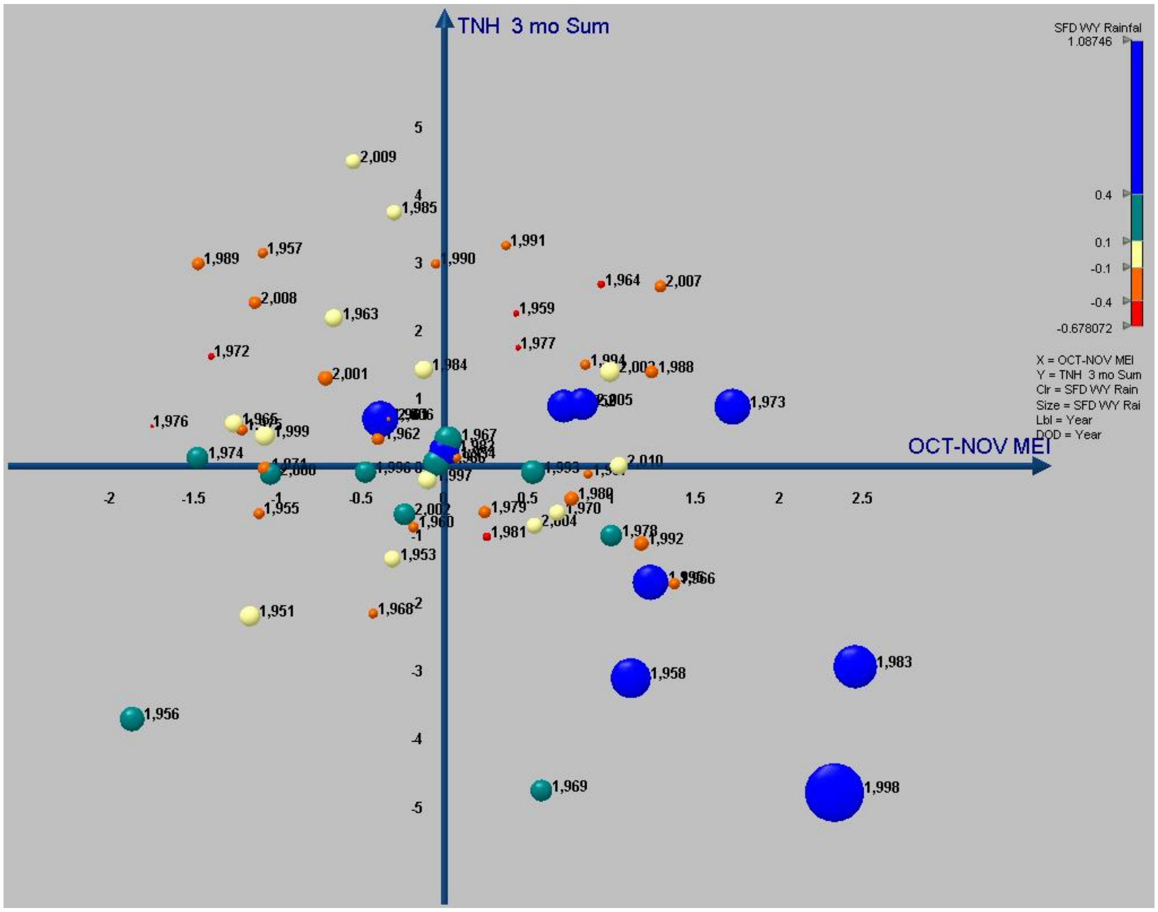

Figure 15 Fall MEI index versus Dec- Feb TNH index. Note that the wettest years all have a TNH index of less than 1. The driest years have a TNH of greater than -2 with a predominance of dry years with TNH greater than 0.

The color scheme was changed slightly here with blue being 140% or greater, teal 110% to 140%, white +- 10% of normal, orange 90% to 60% of normal and red less than 60% of normal. It is interesting to note that the wet and destructive WY of 1995 has plotted over it two years, 1966 and 1992 indicating similar SST distributions but much different rainfall in Ca. Obviously, there are other controlling factors. There does appear to be a somewhat inverse relationship between ENSO and TNH as Mo indicated.

Finally, Figure16 is an attempt to see if there are decadal patterns in wet or dry cycles given that the smoothed analyses of WY rainfall suggested multiyear trends. The break point years were

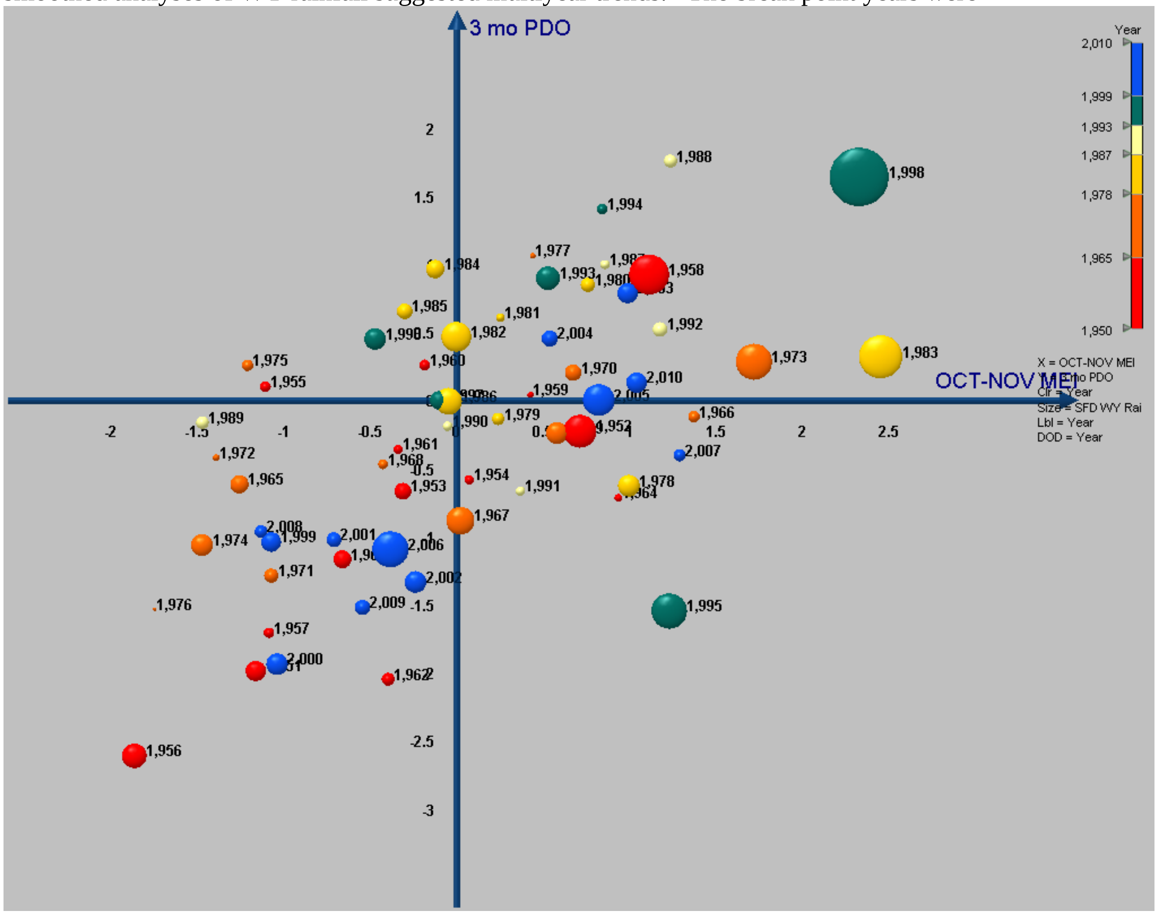

Figure 16 Same as Figure 14 except color coding uses WY designator. Object size is related to WY rainfall anomaly.

determined by using the transitions from wet to dry periods as seen in Figure 4. It should be noted that the period from 1996 to 2006 constituted the wettest 10 year period in SFD WY rainfall dating back to the turn of the 20th century. These years are noted in orange and red. Note that neither MEI nor PDO index isolates these wet and dry periods. The years seem to be split between weak to moderate El Nino's and weak to moderate La Nina's. One does notice however a clustering of years such as the period from 1950 to 1978 being mostly neutral to negative PDO phase (blue), while the years from 1979 through 1998 are mostly neutral to positive PDO phase (green and yellow). This pattern then transitioned back to negative about 1999 but interrupted by the El Nino of WY 2003 with the El Nino persisting into WY 05 before transitioning back to neutral to negative PDO and La Nina conditions from 2007 to 2009, the latest drought period in northern California.

4. <u>COMPOSITE REANALYSIS</u>

It is informative to composite those WY's that are well above normal, greater than 140%, and those WY's that are well below normal, less than 60% of normal based on using SFD gage since 1951. Since the position of the jet controls the storm track and tropical SST's influence the extent and latitude of the jet in winter these two fields are composited. The jet can be represented by the 200 mb zonal wind. Figure 17 is a composite of all wet years using the criteria above. The years used are shown in the composite.

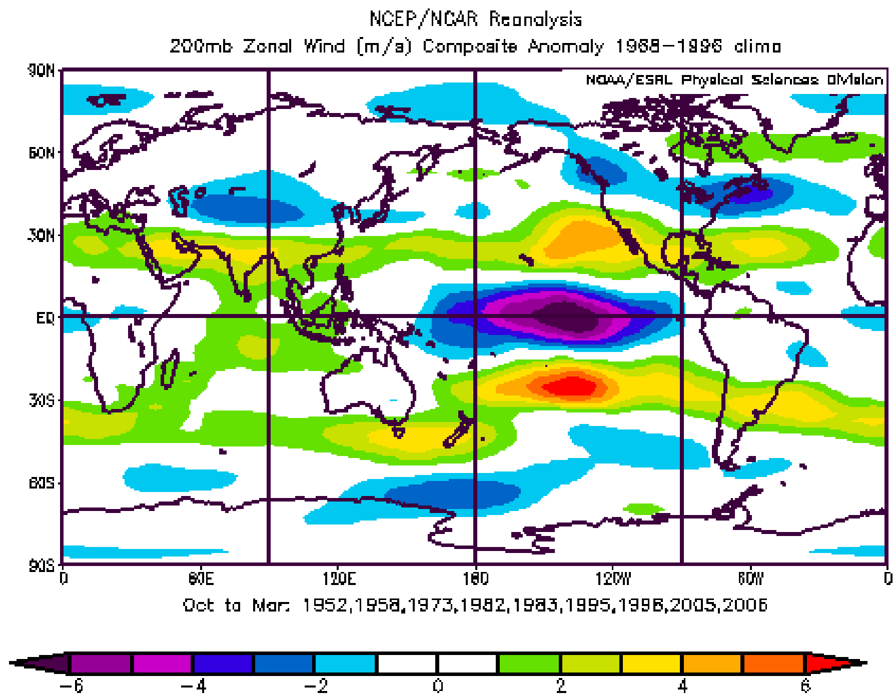

Figure 17 200 mb zonal wind for Oct- Mar for the WY's shown. Note the extension of the East Asian jet with a maximum just west of California. The strong easterly anomaly indicates strong divergent flow over the El Nino 3-4 region typical of strong El Nino's.

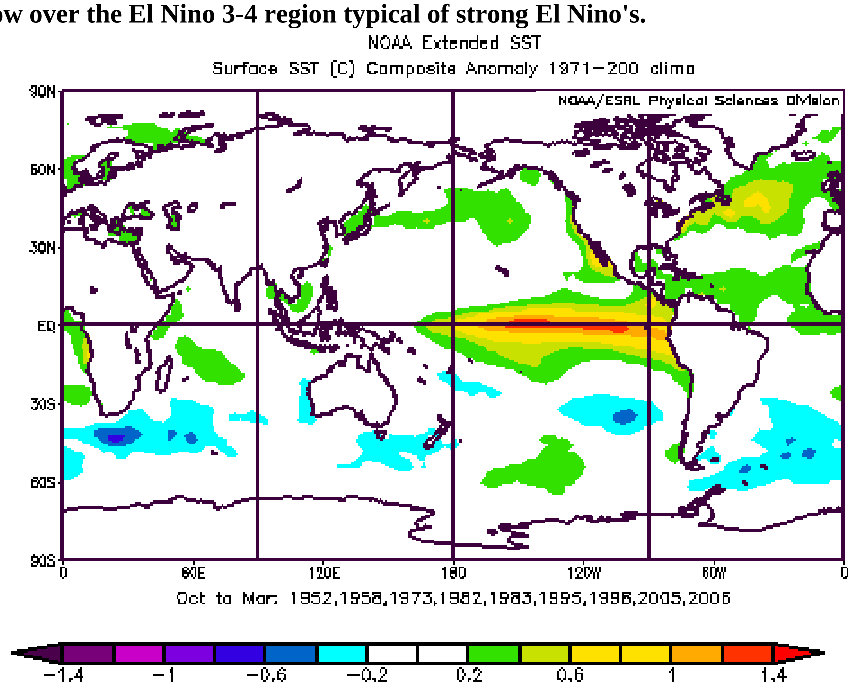

Figure 18 Composite SST's as per Figure 15. Note strong Nino 3-4 SST's.

Figure 18 is the corresponding composite SST analysis. One can see a dominate El Nino signal both in the SSTs and response of the jet to the strong convection over the warmer SST's helping to extend the jet across the entire Pacific.

Figure 19 and 20 represent the very dry years since 1951. These composites would indicate a stronger relationship between SST's, strength and extent of East Asian jet, and tropical SST's.

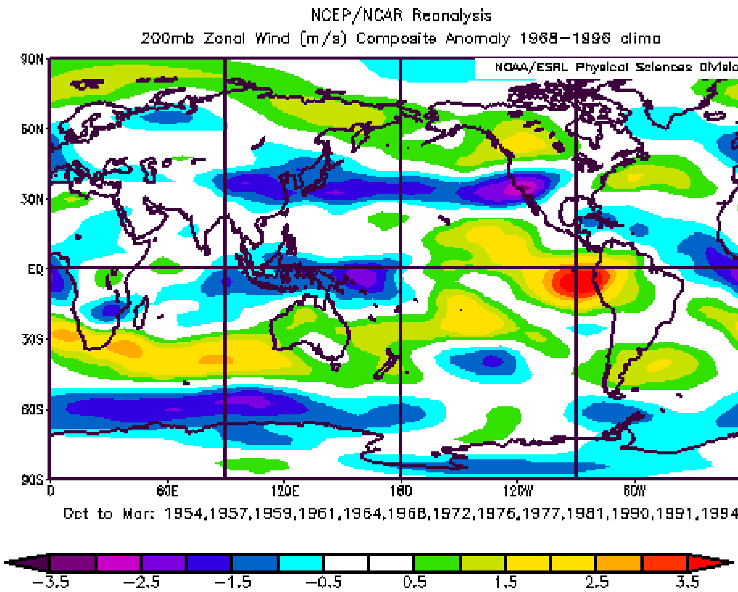

Figure 19 Same as Figure 17 but for SFD WY's of 60% or less precipitation. Here note the northern displacement of the jet and corresponding divergent flow over the western tropical Pacific typical of La Nina conditions. Anomalous low zonal wind is seen over California.

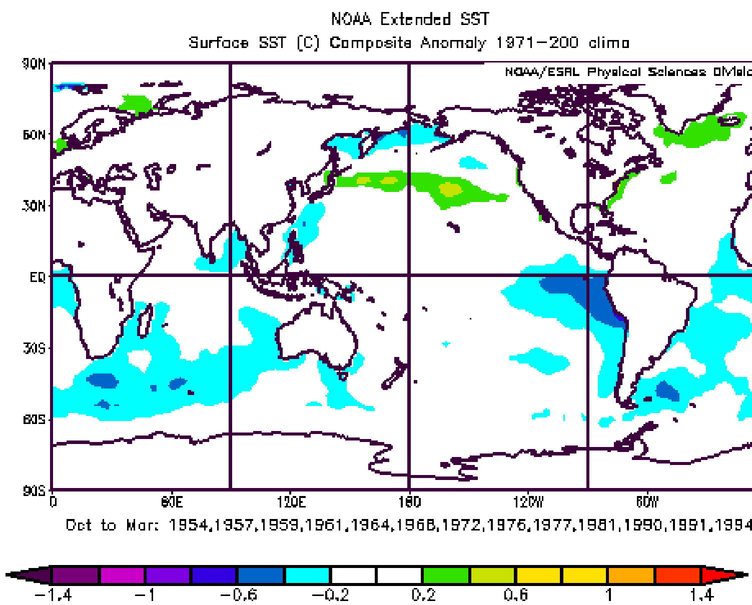

Figure 20 Same as figure 18 but for WY's with less than 60% of average rainfall. Note a rather strong Nino 1-2 cold signature.

4. CONCLUSIONS

Northern and central California have been shown to experience periodic dry periods that generally align with colder SSTs in both the tropical mid/eastern -Pacific (La Nina) and eastern Pacific basin associated with the negative phase of the PDO. The wettest years are most closely associated with the warmest mid/eastern-Pacific(EPAC) tropical waters (strong El Nino) and warmer eastern Pacific basin SST's (positive PDO). Major dry periods occur with a frequency of about 1 every 15 years as seen in the 3 independent WY rainfall data sets analyzed. There appears to be more frequent but shorter duration dry periods during the negative phase of the PDO then positive phase. This can be seen during the years 1945 to 1979 and again during the most recent period from 1999 through 2010.

In analyzing individual WY rainfall data such as San Francisco downtown, there appears little skill in predicting the WY outcome based solely on looking at the fall PDO and/or MEI indices. The exception is strong El Nino's classified by a fall MEI of 1.5 or greater and resultant above normal WY rainfall. Another but not as strong a predictor is a combination of a fall MEI of -1.5 or less and neutral to negative PDO index and resultant below normal rainfall.

There are singular years that have experienced major flooding that do not necessarily fit these categories. These years can experience singular events of very large magnitude, such as December 1955 and February 1986, that can contribute a large percentage of the WY rainfall even during strong La Nina's and negative PDO events. These are very much the exception however. Certainly there are other forcing mechanisms that contribute to wet and dry WYs. It was noted that the conventional ENSO or EPAC ENSO does correlate well with the TNH index for the winter months December through February. This index does help differentiate wet from dry years when plotted with MEI index but does not explain all wet or dry years observed in the 60 year sample. Late winter and spring wet periods could explain several wet WYs like 2006, when, following the very wet December 2005, March 2006 was over 200% of normal and produced local flooding along the central Coast (San Francisco County declared a disaster area due to landslides). It has been noted in CPC analyses that a wet spring usually follows a moderate to strong El Nino even if the temperature signal in the El Nino 3.4 region have cooled.
http://www.cpc.noaa.gov/products/precip/CWlink/ENSO/composites/elnino.mam.precip.gif

Further studies are needed to clarify the outlier years and see if other factors are at work. One such factor could be the Madden Julian Oscillation or MJO that has been known to contribute to flooding (Reynolds, 2008). This may explain some very wet years that are close to the origin in Figure 12 when MJO is thought to be most active. WY's 1986, 1996 and 2005 all were active MJO years with MJO a significant contributor to the major flooding that occurred during these winters in northern California.

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